Status of ion-optics for the Super-FRS*

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Introduction

While the basic ion-optics for the Super-FRS were already established some years ago [1], several changes to the magnet layout have necessitated re-optimizations. Three baseline ion-optics files corresponding to the High Energy, Low Energy and Ring branches should be kept up-to-date. Since the main "work-horses" for the Super-FRS ion-optics are GICOSY [2] and MIRKO [3], translations between the respective input files are frequently made. Various improvements to the translation programs have been made over the last few years. Besides which, COSY-Infinity [4] is also used and has to be maintained. Furthermore, the example files for the simulation programs MOCADI [5] and LISE++ [6], which are based on the transfer matrices generated by GICOSY, need updating if the ion-optics change.

Since many users need, in particular, MOCADI and LISE++ simulations to plan beamline equipment (such as detectors, slits, focal-plane chambers) as well as future experiments, it is convenient to make template input files available for download on a website [7].

Lattice changes

One change affecting all of the Super-FRS ion optics has been the revision of the radiation-resistant quadrupoles after the production target. The revised first quadrupole FPF1QT11 has a smaller aperture and is shorter than the original design. FPF1QT12 on the other hand is longer, but has the same pole gap as before. Importantly, both magnets are further from the target in order to make room for the target chamber, flanges, bellows and pillow seals. Monte Carlo simulations show that while the nominal horizontal angular acceptance is reduced from the "standard" 40 mrad to 38 mrad, the effect on the overall transmission to the end of the Super-FRS is reduced by less than 1%. The change in quadrupole fields also has affected the $2^{nd}-$order corrections. With the usual vertical focus condition at FPF2 for 20 Tm beams, the normal-conducting sextupole magnet FPF2KS11 is pushed slightly beyond its limit in order to correct fully the [A,DD] aberration. By moving the y-focus somewhat beyond FPF2, the required field in FPF2KS11 is reduced and 20 Tm beams can be again fully corrected to high order.

Additional space for detectors and a "slow-down" degrader was needed at the FLF2 focal plane (end of the Low Energy Branch). The previous drift space of 2 m was doubled to 4 m. The ion optics for the Energy Buncher was verified with this increased drift space.

The layout of LEB Energy-Buncher/Spectrometer has been revised. It consists of two dipole stages deflecting the beam in opposite directions, forming an S-shape (Fig. 1). There is a cross-over in the ion trajectories between the two dipole stages so that the resolving power adds together. The final adjustment to the lattice has been the addition of three vertical steerers, which are included in the common quadrupole-sextupole cryostats.

The first dipole stage of the LEB Energy Buncher can be operated as a large acceptance spectrometer for HISPEC/DESPEC [8]. Another mode is to use the Main Separator of the Super-FRS as an "Analyser", coupled and dispersion-matched to the LEB, the ion-optics of which is changed to an "Energy-loss Spectrometer". In this way one obtains very high resolving power [9], despite the large emittance of RIBs produced by fragmentation or fission.

Simulations with MOCADI

The possible loss in beam transmission due to the deflection of dipole vacuum chambers under atmospheric pressure was considered. For the super-conducting dipoles, the deflection is negligible ($\leq$ 1 mm). For the radiation-resistant dipoles in the Pre-Separator, the vacuum chambers must be large enough horizontally to accommodate various charge states of the beam, and ANSYS calculations [10] have shown that the transverse deflection of these chambers can be up to 5.7 mm. However, even such a reduction in the vertical acceptance gives $< 1\%$ transmission loss.

Certain experiments proposed within the Super-FRS collaboration [11] require light RIBs, e.g. ^{24}Ne, slowed-down to Coulomb-barrier energies. The energy distribution and transmission of such ions produced by fragmentation and slowed by achromatic or mono-energetic degraders have been calculated with MOCADI. In addition, the feasibility of experiments using such secondary beams to bombard "stack" targets within a gas cell to produce heavy ions of interest to SHE research [12] has been studied.

Magnet field quality calculations

The availability of random numbers and unlimited order calculations have made COSY-Infinify a useful Monte-Carlo tool to study magnet misalignments [13] and the field quality of vertical steerers in the Super-FRS. In the latter case, dummy elements with sextupole (B_6) and de-

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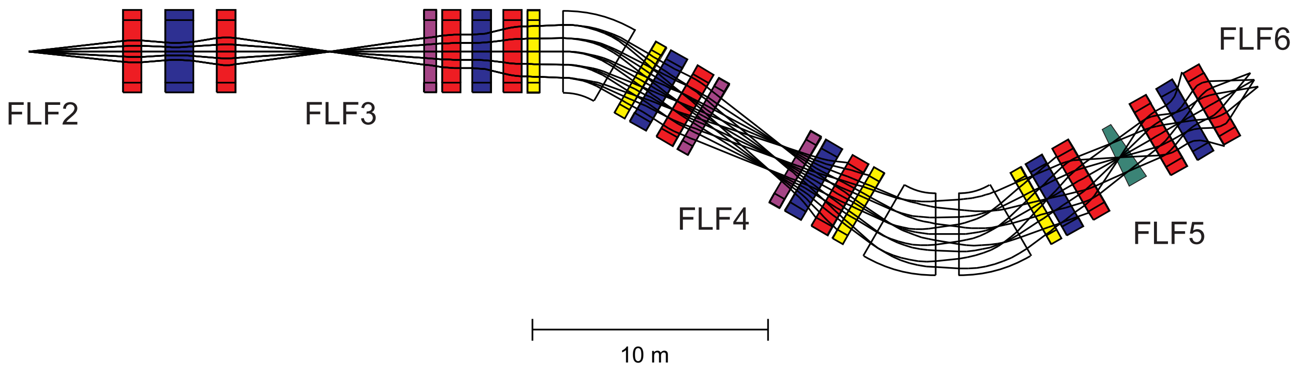

Figure 1: Revised layout of the LEB Energy Buncher, starting from the exit of the Low Energy Branch of the Super-FRS (FLF2). The colour scheme is: x- and y-focusing quadrupoles (red and blue, respectively), sextupoles (yellow), vertical steerers (purple). The mono-energetic degrader is at FLF5 (green wedge). The cryogenic stopping cell would follow after FLF6. The beam trajectories are for an emittance ϵ_x of 255 mm mrad and a momentum spread of $\Delta p/p = \pm 2.5\%$.

capole (B_{10}) random fields were used in place of actual steerer magnets. The strength of the contaminating fields was stepped from zero up to a value where there was a significant loss in resolving power of the fragment separator. For each step, a loop of 50 iterations with different random numbers was used to average out fluctuations in the resolving power (see Fig. 2). The maximum allowable contaminating field is chosen as that resulting in no more than 1% loss in resolving power (red line in Fig. 2). The result, $\Delta B_6/B_2$, where $\Delta B_6 \approx 1.4 \times 10^{-3}$ T and $B_2 = 0.2$ T for 20 Tm beams, showed that the field quality previously specified in the Super-FRS Parameter List of January 2014 could be significantly relaxed.

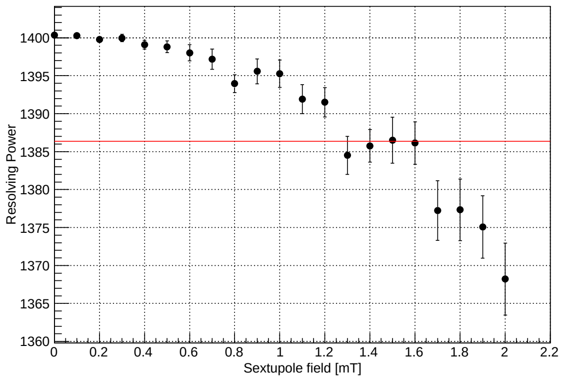

Figure 2: Second-order momentum resolving power at the dispersive focal plane FMF2 against sextupole fields (in millitelsa) in vertical steerer magnets. The error bars are the standard deviation of 50 calculations at each sextupole field strength. The red line represents 99% of the resolving power with no sextupole field.

MIRKO [3] has been extended espcially for the FRS and Super-FRS, and has been used in a somewhat similar way as above, to establish the required field quality of the Energy Buncher dipoles, quadrupoles and sextupoles. With MIRKO, the width of the projected image at the achromatic focus can be used as a quality factor.

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